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EFFECT OF SECONDARY REFLECTOR ON THERMAL PERFORMANCE OF LINEAR FRESNEL CONCENTRATED SOLAR COLLECTOR

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ABSTRACT

Thermal performance of a low cost linear Fresnel solar collector with an absorber tube and a secondary reflector has been studied. The design was made with a compact geometry with optimum optical efficiency. The focal point was determined through iterative methods. The absorber characteristics were studied to determine the best factors that can improve efficiency of the system. The black coated absorber was investigated to achieve better heat gain and efficiency. The increase in heat transfer, fluid flow rate improves the thermal efficiency. Further, the overall efficiency of the system is increased by implementing a secondary reflector by 10%.

KEYWORDS: Linear Fresnel Collector, Parabolic Dish, Solar Collector, Secondary Reflector, Absorber Tube & Concentrated Collector

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Original Article

INTRODUCTION

Energy conservation is a very important topic under which many researches are being conducted to optimize and improve systems to utilize the available energy effectively. One of the best and popular ways to utilize energy without depleting resources is by harnessing the solar energy. Solar Panels are used to convert the sun's rays to electricity. Solar panels are relatively expensive and hard to maintain on a regular basis when considering domestic applications. A better way would be to construct a water storage unit fixed at a focal point of many reflectors. The concentrated beams from every local reflector would accumulate to heat up the water storage unit to potentially convert water into steam, and hence mechanically rotate a turbine to generate electricity. Domestic use of hot water is an essential part of many human beings. This application knows no bounds for its various uses like cooking, cleaning, bathing and washing clothes. Compact solar collectors can be designed and fabricated to meet their needs which can cater to individual houses.

Concentrated solar power (CSP) plants have invited wide attention in various sunlight-rich regions around the world, including India. An integration of two different solar collector fields; linear Fresnel reflector (LFR) and parabolic trough collector (PTC) field are carried out by Nayak*et al.* [1]. Barbón et al. [2] addressed the problem of the mathematical design of LFR. The optimization of the relative position concerning the primary reflector and the size of the single absorber tube are both addressed. Saxena et al. [3] a comprehensive numerical model to study the effects of key parameters were investigated. A quantum of research works was carried out on the optical design and the thermal performance of a parabolic dish, trough and LFR collectors [4-6]. Improved heat exchange and or storage at the receiver focus is the sole aspect of such studies through energy and energy.

Concentrated solar collectors and receivers with their potential applications are reviewed in the earlier works [7-9]. The effective utilization of solar energy is beneficial for the thermal management of the buildings [10]. The effect of temperature distribution and the thermal management of solar receivers are investigated to provide a uniform heat storage [11-18] The parametric study of the solar collector produces useful findings before going for the fabrication of the real-time solar collector [19 -21]. The scale-up linear Fresnel collector and effect of secondary reflector were investigated in the past works [22-24]. In this work, a low cost linear Fresnel collector is constructed with imaging mirrors and the effect of a secondary reflector over the absorber tube is reported.

MATERIALS AND METHODS

The design is proposed to be easy to construct a compact size solar collector. The fixed width method is implemented. The height of absorber is fixed. Concerning the height, factors like the distance of the mirrors from the centre line of the absorber and the angle of tilt for every reflector are calculated using a theoretical approach using implicit equations with required iterations. The material of the pipe selected is copper as it is highly conductive. Radiative heat can easily conduct through the copper tube. The two pass U tube configuration is considered to allow maximum heat to be transferred from the pipe to the working fluid. Two X-Frames were made to hold the U tube over the series of reflectors. The secondary reflectors were easily placed on top of the U tube. Two tanks were used to act as the supply and collection of water as the working fluid. Both tanks were insulated. The supply tank was kept at two different heights that can offer two different flow rates. Temperature readings were recorded at two different flow rates to determine at which flow rate more heat transfer takes place and offers better efficiency. The mirrors acting as reflectors were allowed to tilt anytime with the help of a screw. Two methods are usually used to design a Linear Fresnel Solar Collector by changing the width and angle of each and every mirror strip and by keeping the widths of each and every mirror strip same and constant and by varying the angle.

With the values, the collector was fabricated. Neem wood was used to make a frame which is normally used to house the mirrors. A frame of size 1.2 x 1.4 m^2 was fabricated and 10 PVC pipes were placed on the frame. Araldite was used to stick the mirror on the PVC pipes. The PVC pipes were placed on the frame with a nut and bolt assembly. The tilting of each mirror row is tilted through the nut by a spanner. The angle of tilt is adjusted for each mirror to focus on the absorber tubes. The reflector is the main part of the Linear Fresnel Solar Collector System, which is used to reflect the sun rays onto the focus line. The reflector's frame is made out of neem wood and has a dimension of 1.4 x 1.2 m^2. It houses 10 strips of mirrors which is tilted at a certain angle so that the rays are focused on the receiver. The mirrors are stuck on the top of the PVC pipes which run through the length of the frame. The PVC pipes are housed in the frame with the help of nut and bolt assembly. There are other frame which is in the shape of 'X'. It is placed on either side of the Reflector. The main use of this frame is used to support the receiver and the secondary reflector.

The width of each the mirror strip was fixed at 10 cm and the length of it was fixed at 108 cm. Ten mirror strips of these mirrors so that the area covered by these strips is 1.08 m^2. The focal point was fixed at 50 cm from the base of the collector. Before proceeding to the calculations, a few assumptions must be taken into account; the concentrator is perfectly tracked, the mirror elements produce specular reflection and solar radiation is perpendicular to mirrors.

The distance between adjacent mirrors is given in the Equation (1).

$$S_n = W \sin\theta_{n-1} \tan(2\theta + \xi_0) \quad (1)$$

$$Q_n = Q_{n-1} + W\cos\theta_{n-1} + S_n \tag{2}$$

$$\theta_n = 0.5 \tan^{-1}\{[Q_n + 0.5W\cos\theta_n]/[f - 0.5W\sin\theta_n]\} \tag{3}$$

Where,

Q – Distance between the first mirror and centre of frame.

W – Width of the mirror (constant) = 10c

F – Height of the absorber (focal line) = 50cm, from the base of the reflector.

S – Distance between adjacent mirrors.

ξo – Vertical tilt = 13 (at Chennai.

θ – Angle of tilt for the reflector (varies for each reflector).

By substituting the values, a set of iterative equations is solved. The result obtained for the time is at 12 noon. With the help of this, the angle for other times can be found out in a trial and error basis. Table 1indicates the iterative process. The starting value for the iteration process is zero.

Table 1: Calculated Values for the LFR

Mirror No.	Tilt Angle of Reflector in Radians (θ)	Tilt Angle of Reflector in Degrees (θ)	Shift Between Mirrors (cm)	Distance of Mirror from the Centre (Cm)
1	0.14572839	8.34962211	0	10
2	0.23366154	13.3878202	1.34555770	21.23956166
3	0.30369937	17.4006923	2.14548017	33.11329304
4	0.31877381	18.2643943	3.67252488	46.32818508
5	0.37465217	21.4659881	4.09492586	59.91931514

A copper tube of the outer diameter 10mm was employed to pass water through absorb the heat flux available at the surface of the absorber tube. The size was selected based on the intercepts made on the focus plane by the strips of mirrors. The size should be between the smallest intercept and the largest intercept of the sun rays which is focused on the plane by the reflectors. A multi pass kind of receiver was employed. Gas welding of the copper tubes was performed to provide the second pass. The receiver is coated with standard black paint to increase the efficiency of the system by increasing the temperature transfer between the outside and the inside of the receiver. The temperature of the water is first measured using the digital thermometer in the tank. The water is allowed to pass through the U tube and simultaneously the water is getting heated. The hot water is collected in the sink and its temperature is measured again using the same device used earlier. The system comprises a secondary reflector situated above the series of plane mirrors. This is used to converge the light onto the U tube to increase the intensity of heat.

Figure 1: Photographic View of Linear Fresnel Collector Experimental Setup

A secondary reflector is used to reflect the sun rays, not incidentally on the receiver and reflect them back to the receiver. A sheet metal is used to make this reflector. It is very cheap, easy to fabricate and has good reflective properties. The shape of this should be a half-trapezium so that the rays are reflected back to the receiver. The secondary reflector increases the heat transfer to the water and hence improves the efficiency of the system. The inlet and outlet temperatures of the water is measured with the help of a digital thermometer. The main advantage of this type of the conventional ones is the quick response time and the high accuracy. The range of this thermometer is -5^o to 110^o Celsius. The instantaneous solar radiation is required to find the efficiency of the system. This instantaneous solar radiation is found out using a Pyranometer. It provides the radiation in m/Volts and it is then converted into Watts/m^2 using simple calculations.

Table 2: Specifications of Linear Fresnel Collector

Equipment	Specifications
Dimensions of Linear Fresnel Solar Collector (m)	1.2x 1.4 x 0.01
Outside Diameter of Absorber Tube (mm)	10
Supply and storage tank capacity (liter)	5
Secondary Reflector (m)	1.2

The outdoor experiments are conducted in two cases as with and without a secondary reflector over the black chrome coated receiver. The readings are taken from 11:00to 14:00 with 15minute intervals. The flow rate is 2 liters of water per minute. The temperatures of the fluid and receiver surface are measured with K-type thermocouples. A digital flow meter is used to regulate the HTF flow rate. The outdoor readings are taken for three consecutive days for the repeatability for both cases.

Output Power, $Q_o = \dot{m} * C_p * \Delta T$ (W) (4)

Input Power, $Q_i = I_r * Area$ (W) (5)

RESULTS AND DISCUSSIONS

The secondary reflector was placed on top of the U tube which converges the rays of light towards the U tube. The same experiment was repeated and the inlet temperature, outlet temperature of the water and the Irradiance were recorded and tabulated. During the next set of six days, the U tube was painted with black coating. Black coating can improve the absorptivity of a surface and no secondary reflector used. The same experiment was done. Finally, during the days, the secondary reflector was also used with the black coated copper tubes and the readings were all recorded. All the readings were tabulated and an instantaneous efficiency was calculated and plotted against time corresponding to the

radiation. For every 15 minutes the mirrors were tilted to focus the light on the absorber. This allowed for more heat input and better results. For the first six days the set up included only the copper tube without a secondary reflector. The six days were divided into two where a faster flow rate was used in the first three days and the slower flow rate was used in the next three days. This cycle of varying flow rates repeated for three weeks. Water was passed through the U tube and the temperature was recorded at the sink and the source.

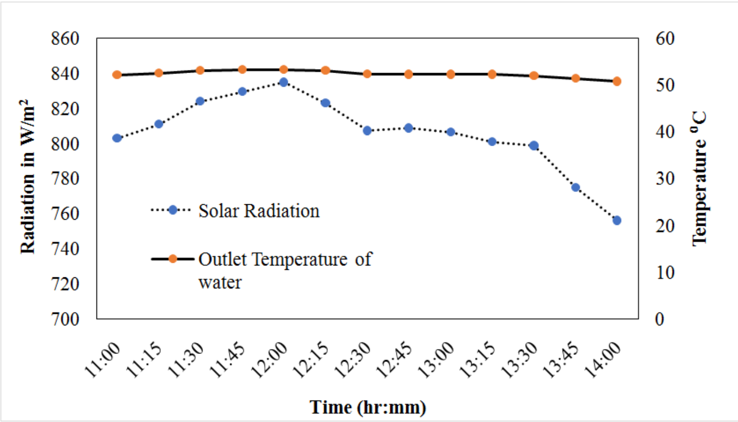

Figure 2: Effect of Solar Radiation on HTF Temperature without a Secondary Reflector on Trial-1

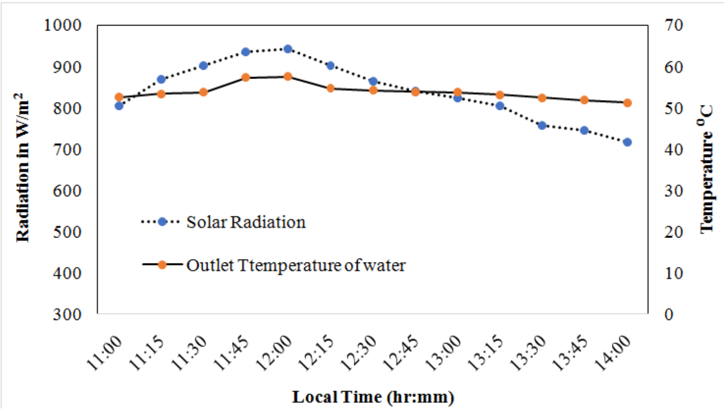

Figure 3: Effect of Solar Radiation on HTF Temperature without a Secondary Reflector on Trial-2

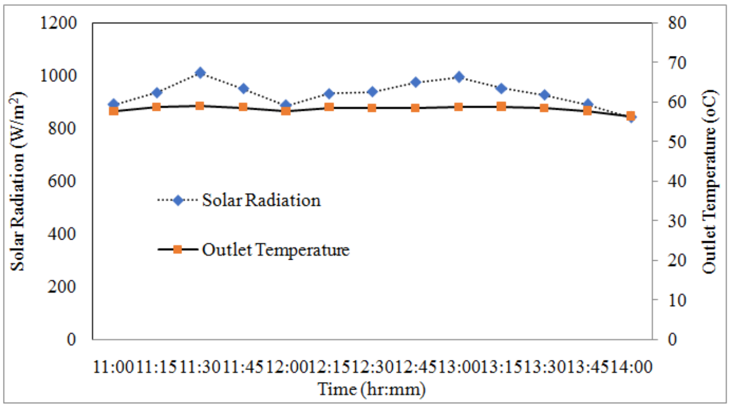

Figure 4: Effect of Solar Radiation on HTF Temperature with a Secondary Reflector on Trial-1

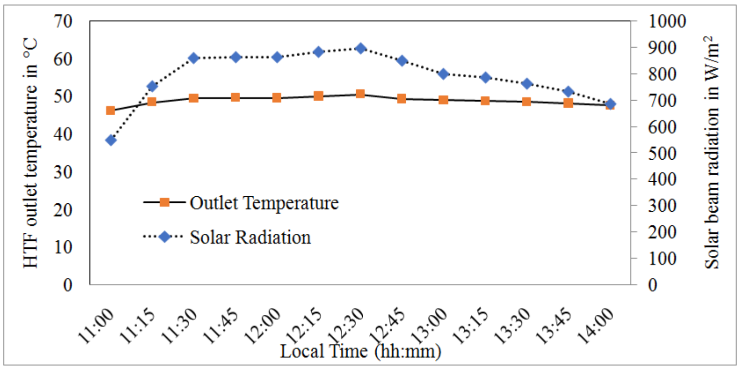

Figure 5: Effect of Solar Radiation on HTF temperature with a secondary reflector on Trial-2

The irradiance was measured using a pyranometer for every 15 minutes from 11:00 hrs to 14:00 hrs. The temperature was recorded using a digital thermometer that can display instantaneous temperature. These readings recorded are used to determine the input and output power. The ambient temperature during the test days is in the range of 32 to 35^{o}C. The average radiation was 820 W/m^2 and wind velocity is in the range of 0-1.5 m/s during all test days. The results are discussed for two days for with and without a secondary reflector. The average energy efficiency of the collector without a secondary reflector is 59.74% on Trial-1 and 58.3% on Trial-2 for the average solar radiation of 810 W/m^2 and 838 W/m^2 respectively (Figure 2 and 3). The ambient temperature for this day is 36 ^{o}C. The average radiation was found out to be 838.3092 W/m^2 and the average energy efficiency was found out to be 69.83% for the Trial-1 with a secondary reflector (Figure 4). On Trial-2, the average efficiency of LER with a secondary reflector was calculated as 69. 49 % (Figure 5). The highest radiation recorded was 897 W/m^2 at 12:30 and the corresponding highest temperature of 59^{o}C was recorded.

The efficiency of the liquid flowing at a faster flow rate was higher than the liquid flowing at a slower flow rate. This was consistent and yet contradicting at the same time. After understanding the dynamics of the system, the working liquid at two different flow rates flow differently. When water flows faster most of the cross section of the tube gets filled due to the incoming thrust with the layers of water behind. This forces the water to maintain contact with the entire surface area from within the tube. This allows for maximum heat transfer to take place. On the other hand, water that was flowing slowly did not experience the same amount of thrust from the succeeding layers of water. The flow was steady and the water remained only in the bottom half of the U tube.

CONCLUSIONS

The average energy efficiency of the newly constructed low cost (less than 75 USD) linear Fresnel reflector with secondary reflector is obtained around 70% under the average solar radiation of 800 W/m^2. The use of a secondary reflector increases the energy efficiency by about 10%. The proposed collector is useful for low temperature applications (<150°C), especially domestic hot water applications. However, the combination of several such collectors will be useful to provide the required amount of heat for the domestic as well as industrial process heating.

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